



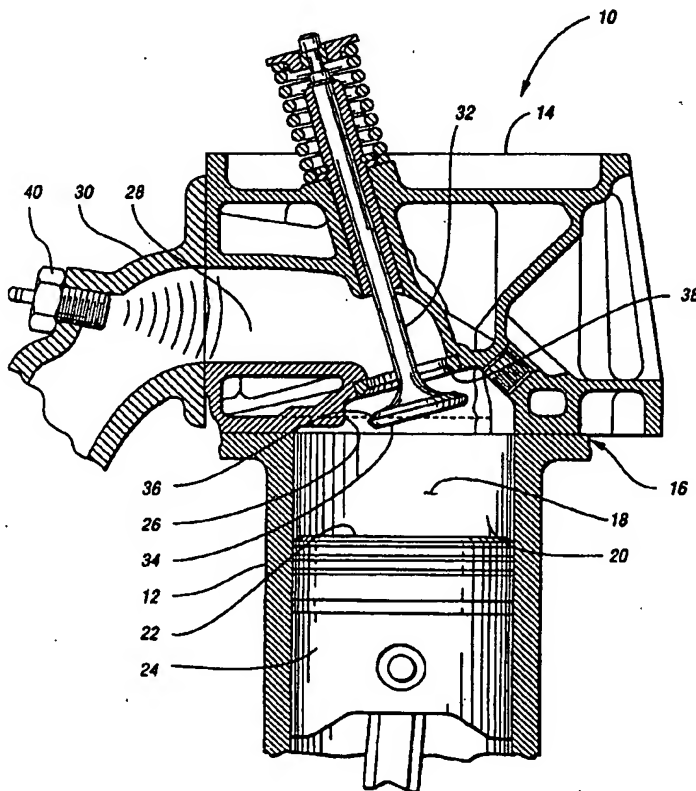
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(21) International Application Number: PCT/US98/17907 (22) International Filing Date: 28 August 1998 (28.08.98) (30) Priority Data: 08/927,987 12 September 1997 (12.09.97) US (71) Applicant: MICHIGAN STATE UNIVERSITY [US/US]; 412 Administration Building, East Lansing, MI 48824 (US). (72) Inventors: SCHOCK, Harold, J.; 2170 Longleaf, Okemos, MI 44864 (US). KOOCHESFAHANI, Manoochehr; 3860 Robury, Okemos, MI 48864 (US). NOCERA, Daniel, G.; 3 Bruce Road, Winchester, MA 01890 (US). (74) Agents: NEMAZI, John, E. et al.; Brooks & Kushman, 22nd floor, 1000 Town Center, Southfield, MI 48075 (US).		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i>

(54) Title: METHOD AND APPARATUS FOR ACTIVE CONTROL OF THE COMBUSTION PROCESSES IN AN INTERNAL COMBUSTION ENGINE

(57) Abstract

The performance of an internal combustion engine is optimized utilizing an electrically controlled driver (40) which is located relative to the intake port (28) to excite the intake charge at a selected frequency, duration and power level which depends on the engine operating condition. The purpose of this excitation is to control combustion by optimizing large scale recirculation patterns of the intake charge within the combustion chamber (18). In particular, this device will provide the effect of optimizing volumetric efficiency at wide open throttle and minimize fuel consumption and emissions at part throttle. An electronic engine controller varies the operation of the drive device as a function of engine operating conditions. The driver excites the intake charge at a frequency of about 5 to 1000 times of the engine speed.



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**METHOD AND APPARATUS FOR ACTIVE CONTROL OF
THE COMBUSTION PROCESSES IN AN INTERNAL
COMBUSTION ENGINE**

Technical Field

5 This invention relates to internal combustion engines having a driver for exciting the intake charge.

Background Art

10 For over 50 years, automotive engineers have been experimenting with acoustic drivers acting upon the intake charge of an internal combustion engine to solve a variety of problems. An example of such early work are a pair of patents, U.S. Patents 2,414,494 (Vang) and 2,454,900 (Bodine). The preceding patents illustrate a series of devices located in the induction system or alternatively, within the confines of the combustion
15 chamber to excite the air fuel mixture at sonic or supersonic frequencies, for the purposes atomizing the air fuel mixture. Substantially concurrently with the work of a William Hancock, U.S. Patent 2,436,570, relating to the use of high frequency pressure
20 pulsations in the intake charge to suppress detonation, Hancock suggested the use of in-chamber as well as intake manifold mounted diaphragm type vibrating actuators for exciting the intake charge in order to create high frequency pressure pulsations with the cylinder.

25 Approximately 10 years after the early work of Vang and Hancock, Ebhardt Hundt of Daimler-Benz, obtained a U.S. Patent 2,737,163 relating to a vibrating driver to be mounted directly within the combustion chamber for ultrasonically exciting the intake charge.

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5 The driver had a specific structure designed to
withstand the pressure and thermal loads resulting from
its direct location in the combustion chamber. The
Hundt device operated at frequencies up to 20 hertz that
was intended to atomize fuel droplets prior to the
10 completion of the compression stroke.

As an alternative to exciting the inner fuel
mixture using a diaphragm type actuator. U.S. Patent
2,949,900 of Albert Bodine disclosed a direct in the
chamber injector which sonically pulsated the injected
15 fuel at 5,000 to 50,000 cycles per second in order to
improve fuel atomization.

Summary Of The Invention

A method and apparatus for the active control
20 of the flow field in an internal combustion engine
utilizing an electronically controlled driver is
provided. The internal combustion engine includes a
head and block assembly defining a combustion chamber
with an intake port and an associated intake valve for
25 cyclically introducing an intake charge into the
combustion chamber. The driver is affixed to the head
and block assembly at a location relative to the intake
port to excite the intake charge at a selected acoustic
frequency duration and energy level in order to optimize
30 large scale recirculation patterns of the intake charge
within the combustion chamber. An electronic engine
control regulates the operation of the driver as a
function of engine operating conditions.

In the preferred embodiment, electronic engine
35 control varies both the frequency, the "on" duration,
and the energy level of the driver as a function of

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5 engine speed and load with the frequency increasing as engine speed increases. Preferably, the driver frequency is optimized to provide the desired recirculation pattern within the combustion chamber.

10 Two alternative charge drivers are illustrated. One driver is located within the intake upstream of the intake valve for exciting the intake charge. The alternative driver is provided by an electro-mechanical actuator which axially oscillates the intake valve during the intake cycle.

15 The object of the present invention is to optimize large scale recirculation patterns of the intake charge within the combustion chamber by perturbing the intake flow through the intake valve opening.

20 An object of the present invention is to maximize volumetric flow efficiency at wide open throttle while minimizing fuel consumption and emissions output at part throttle.

25 These and other objects and advantages of the present invention will become more apparent upon reading the specification in conjunction with the drawings.

Brief Description Of The Drawings

30 FIGURE 1 is a partial cross-sectional side elevation of the first embodiment of an internal combustion engine;

FIGURE 2 is a block diagram of the electronic engine control system;

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5 FIGURE 3 is a timing chart illustrating cylinder pressure, valve left and acoustic drive power as a function of crank shaft position;

FIGURE 4 is a flow chart illustrating the method of optimizing engine performance; and

10 FIGURE 5 is a partial and cross-sectional side view of an alternative engine embodiment of the invention.

Best Mode For Carrying Out The Invention

15 An internal combustion engine 10 illustrating a preferred embodiment of the present invention is illustrated with reference to Figures 1-3. Engine 10 in the preferred embodiment is a spark ignited four cycle engine, however, it should be appreciated that the present invention can alternatively be used on two cycle
20 spark ignited engines as well as two or four cycle diesel engines. Engine 10 is provided with engine block 12 and a cylinder head 14 which collectively form a head and engine block assembly 16. The head and engine block assembly define an internal combustion chamber 18
25 bounded by cylindrical wall 20 of a cylinder bore formed in engine block 12 top 22 of piston 24 and the chamber portion 26 of cylinder head 14.

30 An intake port 28 is formed collectively by an internal passageway in head 14 and in intake manifold 30. Intake valve 32 is of conventional design cyclically opening to allow an intake charge to be introduced into the combustion chamber and closing to isolate the intake port 28 from combustion chamber 18. Intake valve 32 is provided with a head 34 having a

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5 frusto conical valve face 36 which cooperates with a
corresponding frusto conical seat 38 formed at the
junction of intake 28 and cylinder head chamber portion
26.

10 Engine 10 illustrating the first embodiment of
the invention is provided with an electrically
controlled driver 40 which is affixed to the head and
block assembly 16. Driver 40 is oriented relative to
the intake port to excite the intake charge passing
therethrough. In the embodiment illustrated, driver 40
15 is located in the intake manifold 30, however, it should
be appreciated that driver 40 can be alternatively
located within the cylinder head 14 or in a portion of
the intake manifold further upstream than the location
illustrated. Driver 40 is capable of operating at a
20 range of frequencies and power levels which are selected
to optimize the flow of the intake charge through the
valve opening. Due to the sharp edges and the valve,
valve seat and the irregular shape of the combustion
chamber, flow of air fuel mixture into the chamber can
25 be quite unstable and susceptible to external and
deliberate perturbation. The purpose of driver 40 is to
excite the charge at a frequency and amplitude in order
to optimize large scale recirculation patterns of intake
charge within the combustion chamber. Large scale
30 recirculation patterns such as tumble and swirl persist
long after the intake valve is closed and significantly
affect the combustion process. It has been determined
that by acoustically exciting the intake charge as it
flows through the valve, large scale recirculation
35 patterns within the combustion chamber can be
significantly varied.

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5 Driver 40 of the present invention has an
output which varies in frequency and energy level which
varies as a function of engine operating conditions.
Preferably, as engine speed increases, the driver
frequency will increase. The drive frequency of the
10 driver 40 is between 5 and 1000 times the engine RPM.
The precise frequency and energy level of the driver
output needs to be experimentally determined for each
engine throughout the range of speed and load conditions
in which the engine is typically operated. The
15 conventional electronic engine control system used to
regulate fuel injector duration and spark advance is
ideally suitable for also regulating driver frequency,
and power level. Calibration for the driver is
maintained in three-dimensional map or a series of a
20 look-up tables stored in the electronic engine control
and used to generate a driver output signal which is
transmitted to driver 40.

 As illustrated in Figure 2, electronic engine
control 42 has outputs coupled to driver 40, fuel
25 injector 44 and ignition coil drivers 46a, 46b and 46c.
An electronic engine control 42 is provided with a
series of conventional inputs, engine RPM 48, crank
angle position 50, engine temperature 52, mass air flow
(MAF) 53 and manifold absolute pressure (MAP) 54.

30

 As illustrated in Figure 3, the driver 40 need
not be operated continuously. Rather, driver 40 need
only be operated during the intake event and this driver
power can be conserved. Additionally, the frequency and
35 power level of the driver can be varied within each
intake event in order to optimize performance.

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5 The use of driver 40 to excite the intake
charge, enables engine designer to select an driver
frequency and energy level optimizing volumetric
efficiency and power output when the engine is running
at wide open throttle and optimizing combustion
10 efficiency and emissions levels when the engine is run
at part throttle conditions. It is believed that the
driver of the present invention will be a valuable tool
in optimizing engine performance.

15 In calibrating an engine equipped with an
driver to excite the intake charge, the engine designer
must map the engine's performance characteristics,
monitoring fuel consumption, power output and emissions
while varying the frequency of the driver power levels.
This is a particularly complex task since varying the
20 driver frequency and energy level will affect the
combustion and the optimum spark timing. Therefore, at
each selected speed and load condition, an optimum
driver operating signal and spark advance will need to
be concurrently established. Once the engine designer
25 has developed an engine calibration map, the electronic
engine control is then programmed with either in a
series of look up tables using a three dimensional
surface in a manner similar to that used for spark
advance control.

30 In the preferred embodiment of the invention,
when the engine is running in a wide open throttle, the
driver will operate at a selected frequency and power
level selected to maximize volumetric efficiency.
Preferably, when the engine is running at part throttle,
35 a driver will be operated at a frequency and power level
designed to optimize fuel consumption and emissions.

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5 It should be appreciated that a wide variety
of drivers can be utilized in practicing the present
invention. Driver 40 can be an electro mechanical type
or a piezoelectric device. The driver, however, need
not be placed in the intake port, rather, as illustrated
10 in engine 60, shown in Figure 5, the driver 62 may be
used to axially oscillate intake valve 64, thereby
exciting the flow of the intake charge through the valve
opening. Engine 60 utilizes a push rod 66 and a rocker
arm 68 for cyclically actuating intake valve 64.

15 It should be appreciated that a wide variety
of other mechanical mechanisms and micro-electro
mechanical actuators can be used to oscillate intake
valve 64 and the illustration of Figure 5 is intended to
be a mere example of a representative system. Driver 62
20 is located between semi-spherical ball 70 and nut 72.
As driver 62 is actuated, it will vary in thickness
causing the center of rocker arm 68 to be vertically
oscillated which in turn, pivots the rocker arm 68 about
the end of push rod 66.

25 When the valve is lifted as illustrated in
Figure 5, oscillation of the driver 62 will be
translated into axial motion of intake valve 64. In the
embodiment of engine 60, it is desirable to only
oscillate the intake valve when the valve is open.
30 Accordingly, the power will is not to be supplied to the
actuator until the valve is lifted sufficiently from the
seat to avoid chattering, power to the driver will be
terminated prior to returning to the closed position.

35 It is also understood, of course, that while
the form of the invention herein shown and described
constitutes a preferred embodiment of the invention, it

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5 is not intended to illustrate all possible forms
thereof. It should also be understood that the words
used in the specification are words of description
rather than limitation and various changes may be made
without departing from the spirit and scope of the
10 invention.

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5 **What Is Claimed Is:**

1. A multi-cycle internal combustion engine having a head and block assembly defining a combustion chamber provided with an intake port and an associated
10 intake valve for cyclically introducing an intake charge into the combustion chamber, the engine comprising:

 an electrically controlled driver affixed to the head and block assembly located relative to the intake port to excite the intake charge at varying
15 acoustic frequencies and energy levels which are selected to optimize large scale recirculation patterns of the intake charge within the combustion chamber; and

 an electronic engine control regulating the operation of the internal combustion engine varying fuel
20 flow and the driver as a function of engine operating conditions.

2. The engine of claim 1 wherein the driver is located upstream of the intake valve and is provided with a diaphragm for exciting the intake charge.

25 3. The engine of claim 1 wherein the driver is an electro mechanical actuator which axially oscillates the intake valve.

 4. The engine of claim 1 wherein the electronic engine control varies the frequency of the
30 driver as a function of engine, speed and load.

 5. The engine of claim 1 wherein the electronic engine control further varies the duration of the driver as a function of speed and load.

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5 6 The engine of claim 1 wherein the
electronic engine control varies the energy level of the
driver as a function of engine speed and load.

10 7. The engine of claim 1 wherein the
electronic engine control varies in the operation of the
driver within each engine cycle.

8. The engine of claim 1 wherein the
electronic engine control increases the frequency of the
driver as the engine speed increases.

15 9. The engine of claim 8 wherein the
electronic engine control operates the driver at a
frequency 5 to 1000 times the speed of the engine.

20 10. The engine of claim 1 wherein the
electronic engine control operates the driver at a
frequency and energy level selected to optimize the
volumetric efficiency when the engine is run at wide
open throttle.

25 11. The engine of claim 1 wherein the
electronic engine control operates the driver at a
frequency and energy level selected to minimize fuel
consumption and emissions when the engine is operated at
part throttle.

12. The engine of claim 1 wherein the engine
is a four cycle spark ignited engine having a spark
timing regulated by the electronic engine control.

30 13. A four cycle spark ignited internal
combustion engine having head and block assembly
defining a combustion chamber provided with an intake

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5 port and an associated intake valve for cyclically
introducing an intake charge into the combustion
chamber, the engine comprising:

an electrically controlled driver affixed to
the head and block assembly and located relative to the
10 intake port to excite the intake charge at various
selected acoustic frequencies and energy levels chosen
to optimize large scale recirculation patterns of the
intake charge within the combustion chamber; and

an electronic engine control for regulating
15 the operation of the internal combustion engine varying
fuel flow, spark timing and the frequency and power
level of the driver as a function of engine operating
condition wherein the frequency of the driver generally
increases as a function of engine speed and has a drive
20 frequency between 5 and 1000 times the engine rpm.

14. A method of regulating the operation of
a multi-cycle internal combustion engine having a head
and block assembly defining a chamber provided with an
intake port and associated intake valve for cyclically
25 introducing an intake charge into the combustion
chamber, and an electronic engine control regulating the
operation of the engine and varying fuel flow as a
function of speed and load, the method comprising:

exciting the intake charge using an
30 electronically controlled driver coupled to the head
block assembly and located relative to the intake port
to excite the intake charge; and

regulating the operation of the driver
utilizing the electronic engine control as a function of
35 engine operating conditions to optimize large scale
recirculation patterns of the intake charge within the
combustion chamber.

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5 15. The method of claim 14 wherein the
operation of the driver is regulated as a function of
engine, speed and load.

10 16. The method of claim 14 wherein the
frequency level of the driver is varied as a function of
engine, speed and load.

17. The method of claim 14 wherein both the
frequency and the power level of the driver is varied as
a function of engine speed.

15 18. A method of optimizing the performance of
the multi-cycle internal combustion engine having a head
block assembly defining a combustion chamber provided
with an intake port and associated intake valve for
cyclically introducing intake charge into a combustion
chamber, a method comprising:

20 installing an electronically controlled driver
on the head block assembly located relative to the
intake port to excite the intake charge at a frequency
and an energy level selected to effect large scale
recirculation patterns of the intake charge within the
25 combustion chamber;

mapping engine fuel economy, power and
emissions at normally occurring operating speeds and
loads while varying the frequency and power level of the
acoustic device;

30 developing an engine calibration to various
fuel and driver frequency and power level as a function
of operating condition and programming the electronic
engine control to generate a control signal for
regulating the operation of the driver to implement the
35 developed engine calibration.

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5 19. The method of claim 17 wherein the developing of the engine calibration further comprises selecting an driver frequency and an energy level which maximizes engine power output at wide open throttle conditions.

10 20. The method of claim 17 wherein developing an engine calibration further comprises selecting a driver frequency energy level which minimizes fuel consumption and emissions at part throttle engine conditions.

15 21. The method of claim 17 further comprising varying the control signal to the driver within each engine operating cycle to optimize engine performance.

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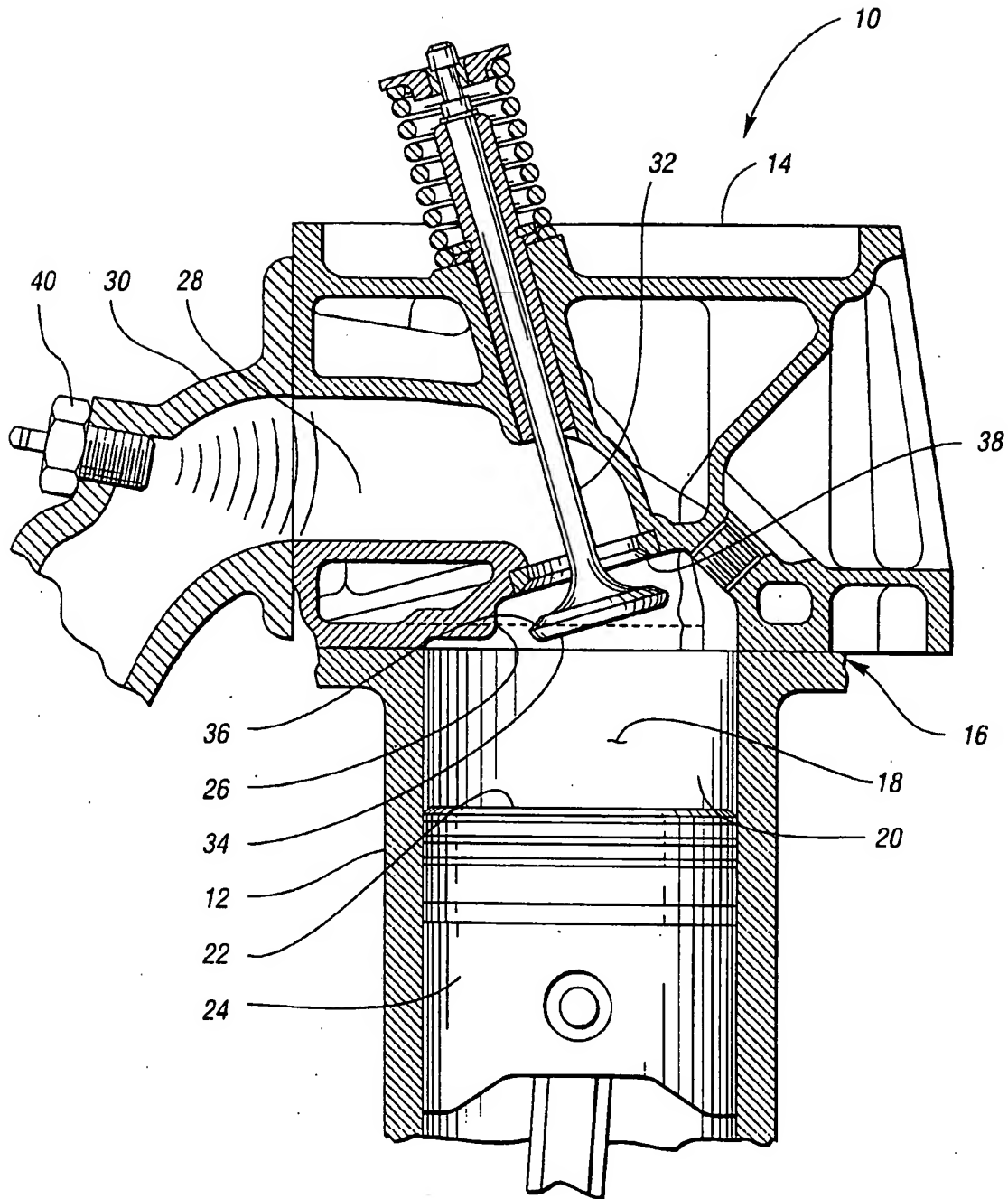


Fig. 1

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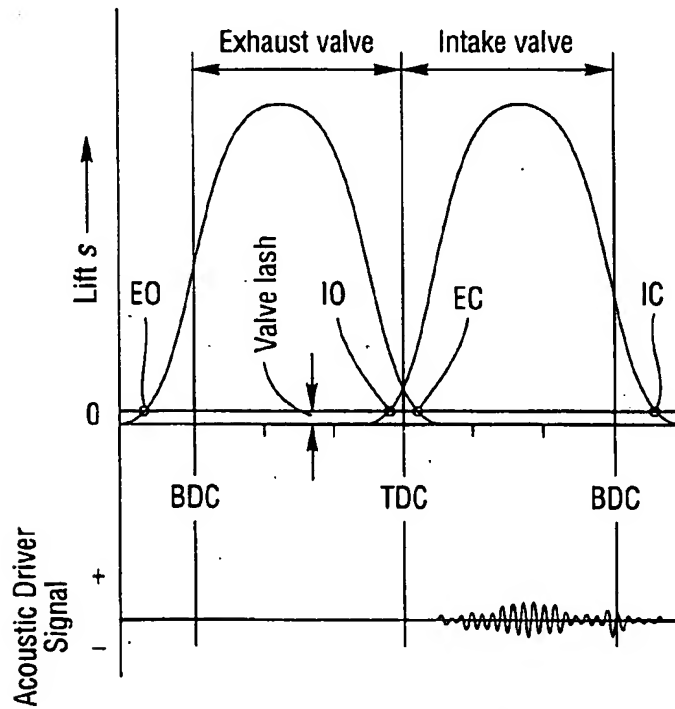
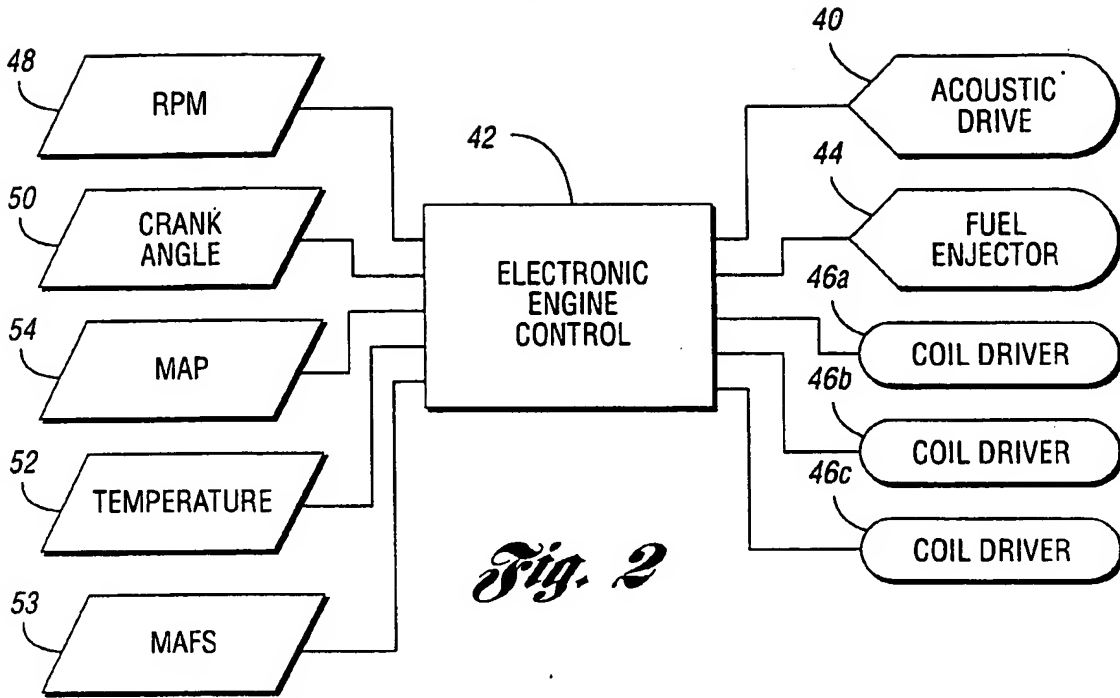


Fig. 3

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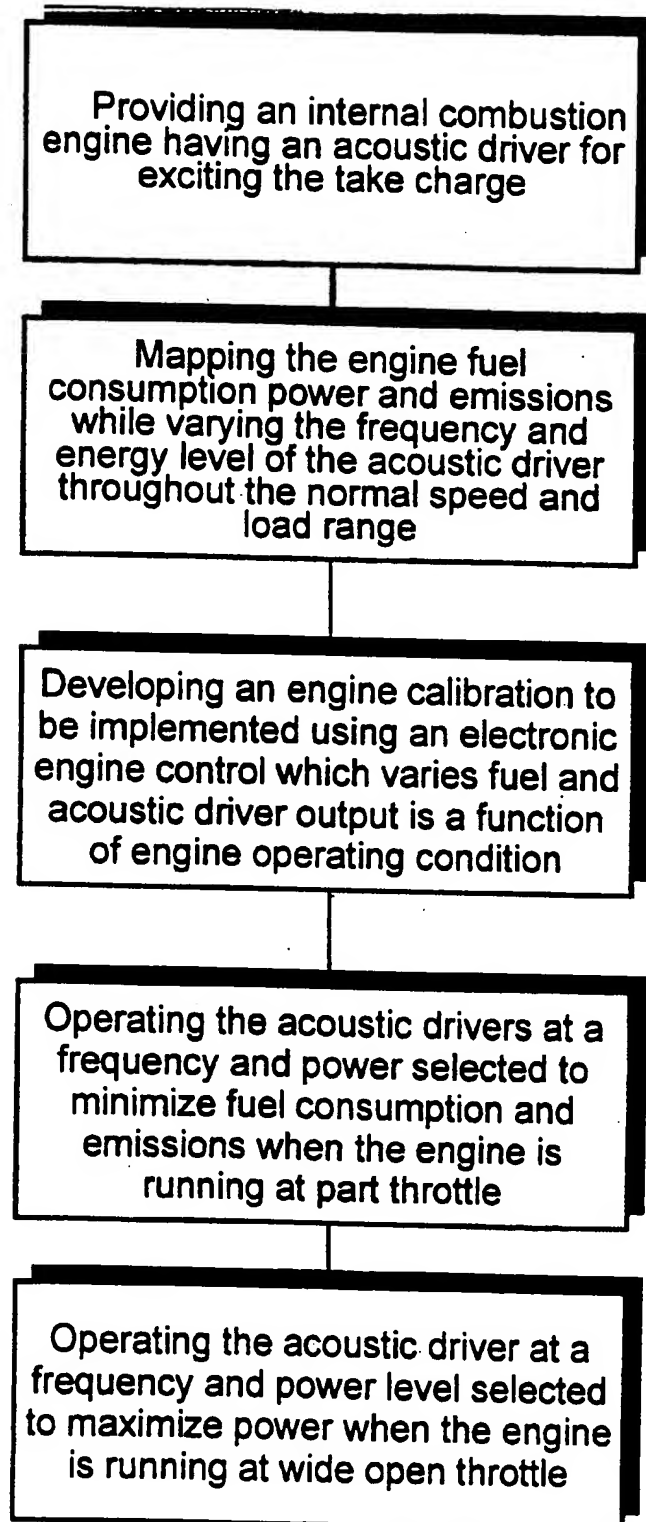
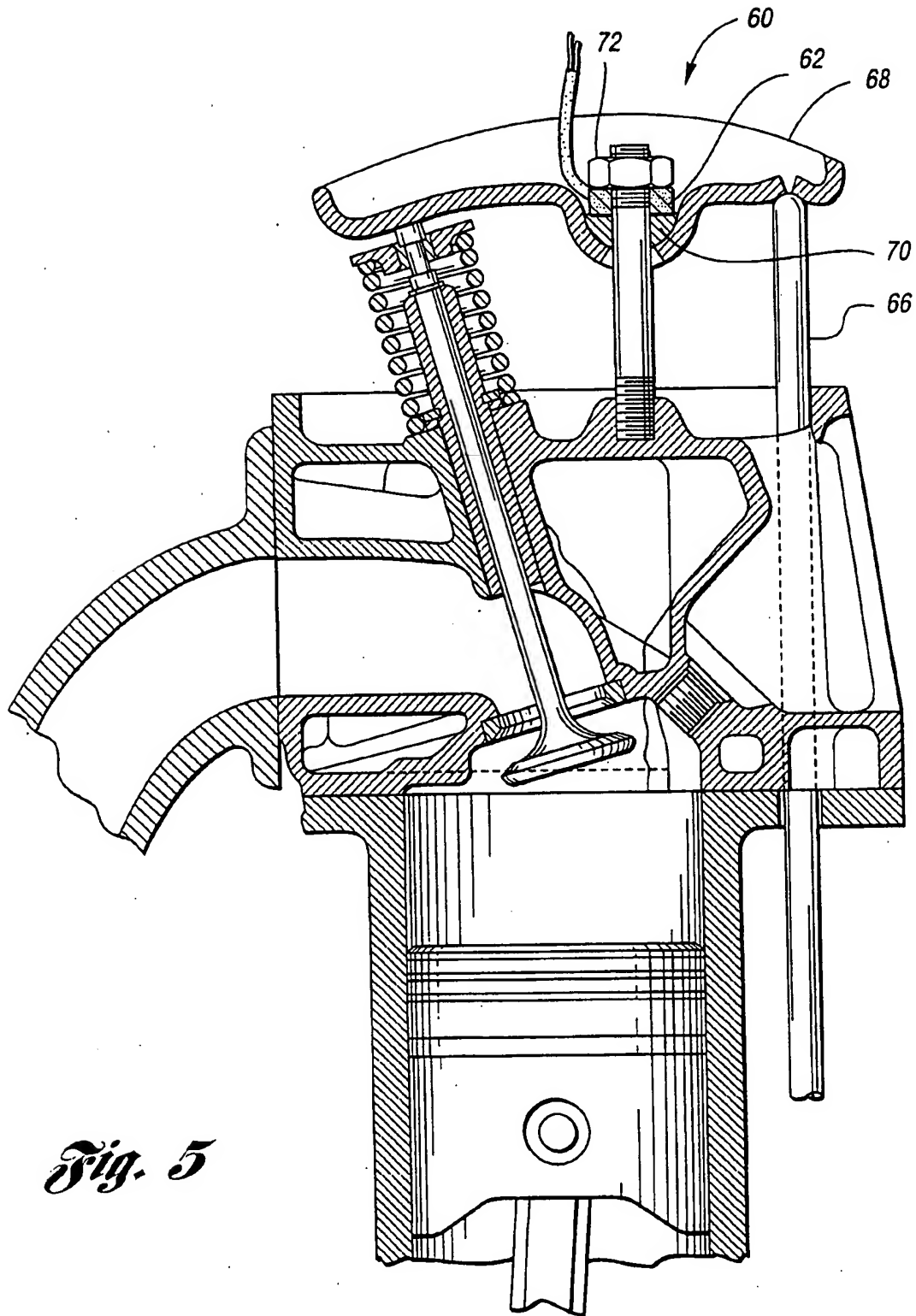


FIG.4

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INTERNATIONAL SEARCH REPORT

Int l Application No

PCT/US 98/17907

A. CLASSIFICATION OF SUBJECT MATTER
 IPC 6 F02B27/00 F02M27/08 F01L1/46

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B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 F02B F02M F01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 492 787 A (FORD MOTOR CO ; FORD FRANCE (FR); FORD WERKE AG (DE)) 1 July 1992 see column 3, line 39 - line 49 see column 3, line 39 - line 49 see column 4, line 51 - column 5, line 31 see figures 1-3	1,2,4-6, 10-12, 14-20
A	---	13
A	US 5 176 114 A (BRACKETT STEPHEN E) 5 January 1993 see column 2, line 59 - line 68; figure 1 ---	1,13,14, 18
A	GB 2 203 488 A (FORD MOTOR CO) 19 October 1988 see page 6, line 9 - line 20; figures 1,2 -----	1,13,14, 18

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

10 December 1998

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

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